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R&D Investment in National and International Agricultural Research

An Ex-ante Analysis of Productivity and Poverty Impact

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ABSTRACT

This paper estimates required investment and its allocation among different regions to maximize agricultural output gains and poverty reduction. The analysis uses a social welfare function to simulate the optimal allocation of research and development (R&D) investment across developing regions (1) to maximize agricultural growth or (2) to maximize poverty reduction at the global level. Due to uncertainties of the parameters used, we conducted sensitivity analyses to evaluate the effect of different values of R&D and poverty elasticities on the optimal allocation of R&D investment across regions. Our simulation results are robust for a wide range of parameters and show that to maximize agricultural output growth in developing countries, R&D investment should be allocated mainly to Southeast Asia and South Asia, whereas to maximize poverty reduction, priority should be given to Sub-Saharan Africa and South Asia.

Keywords: agriculture, growth, optimization, poverty, R&D investment

JEL Codes: C61, O13, O32, O57, Q16, Q18

1. INTRODUCTION

Stagnation in world food production and declining rates of yield growth in main food crops threaten world food security. Increasing constraints in land and water availability and a changing climate have added to concerns about the food and nutrition security of the poor in developing countries. Among the several factors leading to these concerns, a major force is the long-run stagnation or decline (or both) in public research in many poor countries and within the Consultative Group on International Agricultural Research (CGIAR).

Agricultural research has played a key role in promoting production and productivity, thus helping with poverty reduction in developing countries for the past several decades. Compared with returns to other investments, returns to agricultural research and development (R&D) have been one of the highest. However, as we move to a new era, we face new challenges. More than one billion people still live under US$1 per day, and more than one billion people are malnourished.[1] Population will continue to grow, and most of this growth will come from developing countries. The key questions are how agricultural R&D can continue to play the role it has played in the past, how much investment is really required, and how investment can be allocated among different regions to maximize agricultural output gains and reductions in poverty. The objective of this paper is to use a transparent modeling and simulation framework to quantify total research investment required in developing countries (including CGIAR's investment) and its optimal allocation for maximizing productivity growth and poverty reduction. The paper also simulates how efficiency improvement can help to achieve these goals in a more cost-effective manner.

Simulating required R&D investment and optimally allocating it among regions require parameters that causally link agricultural growth to agricultural research investment. The literature includes many studies of production economics whose main focus is the causal relationship between output and R&D investment in addition to conventional inputs such as land, labor, and fertilizer. In an early survey of this literature, Norton and Davis (1981) classify research impact studies into ex-ante and ex-post evaluations and refer to two main approaches: (1) the economic surplus approach and (2) the production function approach, which has been extended to the use of duality and the estimation of cost and profit functions. The economic surplus approach analyses changes in producer and consumer benefits as the result of a research-induced shift in the supply curve. The production function approach evaluates the additional output or the saving in inputs attributable to past investments in R&D by estimating an aggregate production (profit, cost) function model. Alston, Norton, and Pardey (1995) discuss both approaches in great detail. A critical step in both methods is the modeling of the relationship between investment in R&D and the benefits that result.

The approach used in this paper is an ex-ante analysis, but parameters used were from previous ex-post analyses. More specifically, our analysis uses a mathematical optimization model in which an objective function is specified given technology (production function) and resources (land or other inputs) constraints. The approach is particularly useful when there is not enough information to econometrically specify the relationships between agricultural output and R&D or when the range of possible solutions requires modeling seeking behavior rather than relying on projections of past trends. (McCarl 1992).

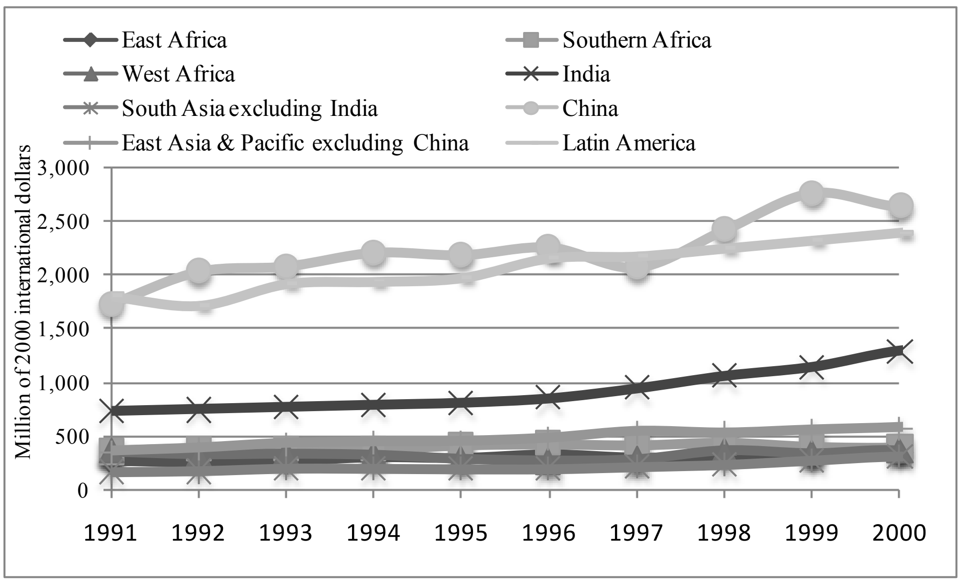
[1] All dollars are U.S. dollars.

2. RESEARCH INVESTMENT, PRODUCTIVITY, AND BENEFITS

This section reviews trends in agricultural R&D spending by both the National Agricultural Research System (NARS) and the international research centers of CGIAR, as well as trends in productivity. It then presents a simple model to simulate the impact of doubling agricultural R&D investments in five years on agricultural production growth and poverty reduction. We deliberately do not attempt to separate the effects of CGIAR versus NARS investments, because these two forces are highly complementary in close partnership. International and national agricultural research must expand in tandem.

In the 1990s, total agricultural R&D spending in developing countries increased from $3.3 billion (1992) to $3.9 billion (2000), or by 2.1 percent annually (Figure 1).[2] This spending was largely driven by Asia, where annual spending increased by 3.5 percent. In Africa, agricultural R&D expenditure grew by a much slower rate of 1.9 percent per year. East Africa's expenditure grew the most, at 4.6 percent, whereas West Africa's grew marginally, at 1.7 percent, and Southern Africa's spending remained constant. Latin America's expenditure grew by only 0.6 percent during this period.

Figure 1. Agricultural R&D spending in developing countries



Source: Agricultural Science and Technology Indicators (ASTI) datasets (2009).
Note: R&D = research and development; USD = U.S. dollars.

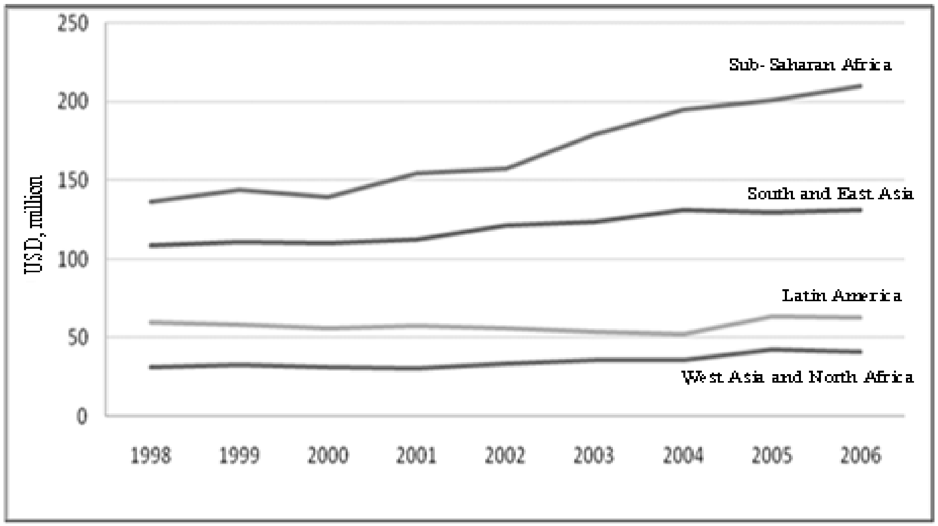
As a result, many countries are sharply divided in capacity to use science to promote productivity growth to achieve food security and reduce poverty and hunger. Today, Asia accounts for 46 percent of total agricultural R&D spending in developing countries, whereas China and India account for 25 and 14 percent of total spending, respectively. Although Africa is geographically large, its share is only 17 percent. Latin America accounts for 36 percent (with Brazil responsible for 41 percent of that share).

For every $100 of agricultural output, developed countries spend $2.36 on public agricultural R&D, whereas developing countries spend only $0.53 (Pardey et al. 2006). This fact highlights the underinvestment in agricultural R&D in developing countries and the gap in generating new technology between rich and poor nations.

[2] All research spending is measured in constant 2005 U.S. dollars. This measure differs from the traditional measure of purchasing power parity or international dollars reported by various Agricultural Science and Technology Indicators (ASTI) reports.

Regarding investment in the international centers, CGIAR funding increased from $337 million in 1992 to $445 million in 2006, representing an annual growth of only 2 percent (Figure 2). In 2000, the CGIAR stand for 9.6 percent of agricultural research spending in developing countries. CGIAR spending is relatively small in Asia and Latin America (representing 6.8 and 4.4 percent, respectively, of their total national system investment) but is large in Africa (23 percent).

Figure 2. Agricultural R&D expenditure by the CGIAR



Source: CGIAR.
Note: R&D = research and development; CGIAR = Consultative Group on International Agricultural Research; USD = U.S. dollars.

Productivity has risen in many developing countries, mainly as a result of investment in agricultural research combined with improved human capital and rural infrastructure (Table 1). In East Asia, land productivity increased from $1,485 per hectare in 1992 to $2,129 per hectare in 2006, whereas labor productivity rose from $510 to $822 per worker. In Africa, the levels of productivity are much lower, and their growth has been slower. In 1992, land productivity in Sub-Saharan Africa (SSA) was only 79 percent of that in East Asia (indicating a 21 percent gap); by 2006, the gap had increased to 59 percent. Growth in total factor productivity (TFP, derived from the ratio of total output growth to total input growth) exhibits even larger variation among regions. From 1992 to 2003, East Asia and Latin America experienced the most rapid growth, at 2.7 percent per year. East Africa had the lowest growth. TFP in other regions grew between 1 and 1.6 percent.

Table 1. Agricultural productivity growth in developing countries (%)

	Land		Labor		TFP
	1992	2006	1992	2006	1992–2003
	(2005 constant US$/hectare)		(2005 constant US$/worker)		Annual growth (%)
East Asia	1,485	2,129	510	822	2.7
South Asia	813	1,156	539	644	1.0
East Africa	503	514	347	351	0.4
West Africa	408	521	601	730	1.6
Southern Africa	255	229	234	190	1.3
Latin America	1,129	1,614	3,294	5,402	2.7
NAWA	785	1,121	1,785	2,184	1.4
Average	846	1,198	591	827	2.1

Source: Authors' calculation based on data from the Food and Agriculture Organization of the United Nations.
Note: NAWA is North Africa and West Asia .

Returns to agricultural research have proved to be very high. On average, the rate of return (ROR) to NARS in developing countries is 60 percent (see Table 2), which is higher than investments in education and roads.[3] The Asia and Pacific region has the highest ROR (78 percent); Africa has the lowest, but even the African RORs are high (49.6 percent). The median ROR exhibits similar patterns among regions; the Asia and Pacific region has the highest, Africa has the lowest, and Latin America falls in between. The ROR for international agricultural research centers (IARCs) in the CGIAR is much higher than that for NARS. In Africa the median IARC ROR is 83 percent higher than for NARS, whereas in the Asia and Pacific region the gap is 72 percent. The gap in Latin America is only 21 percent. This pattern points to the need for investment in increased capacity strengthening of NARS.

Table 2. Rate of return of NARS and IARC

Rate of Return	Alston et al.	Evenson	Evenson and Gollin
	NARS Mean	NARS Median	IARC
Developing countries	60.1		
Africa	49.6	37	68
Asia and Pacific	78.1	67	115
Latin America	53.2	47	39
IARCs	77.8		

Sources: Alston et al. 2000, Evenson 2001, and Evenson and Gollin 2007.
Note: NARS = National Agricultural Research System; IARC = International agricultural research center.

[3] For comparisons of returns to different types of investment, see Fan 2008.

3. THE MODEL

Based on the considerations discussed in the previous sections, in this study we use a mathematical optimization model to simulate the optimal allocation of R&D investment among major developing regions to maximize global agricultural production or, alternatively, minimize global poverty. This approach follows the work by Fan, Zhang, and Robinson (2003) who developed an optimization model to quantify the contribution to aggregate growth from reallocating resources among sectors over time. Fan, Zhang, and Robinson estimated sectorial production functions; by assuming a certain social welfare function, they then conducted simulations to obtain optimal input allocations among sectors.

In this study, we focus on R&D investments instead of conventional inputs and define the optimization problem of maximizing a social welfare function to optimally allocate R&D investment across developing regions. We assume that the level of agricultural output in each region is the result of the use of conventional inputs (land, labor, tractors, animal stock, and fertilizer), which we fix at their base observed level, and the stock of R&D. With inputs fixed, agricultural output then varies with R&D stock. We define R&D stock as a function of past investment in R&D, because there is a time lag between investment and actual impact on production and poverty. The response of output to R&D growth is specific for each region and depends on R&D elasticity values obtained from the literature.

The optimization problem is also solved to minimize the number of poor people across regions subject to each region's agricultural output response to R&D and the response of poverty to agricultural output growth in each region. As in the case of output response to R&D, changes in poverty due to agricultural growth are also defined using poverty elasticities from the literature.

The first optimization problem maximizes agricultural output across developing regions. It maximizes the following welfare function:

Maximize:

$$W_t^{max} = \sum_i [\mu_{i,t} \times \ln(Y_{i,t})] , \qquad (1)$$

whereas for the second problem, the objective is poverty minimization in developing regions:

Minimize:

$$W_t^{min} = \sum_i [\rho_{i,t} \times \ln(Z_{i,t})] , \qquad (2)$$

where $Y_{i,t}$ is region *i* agricultural output in year *t*, $Z_{i,t}$ is the number of poor (under \$1.25 a day or, alternatively, \$2 a day) in region *i*, $\mu_{i,t}$ is the share of region *i* in total agricultural output, and $\rho_{i,t}$ is the share of region *i* in total number of poor.

Both the output maximization and poverty minimization problems are subjected to the same constraints:

$$Y_{i,t} = \gamma_{i,t} \prod_j X_{i,j,t}^{\alpha_{i,j}} \left[RDSK_{i,t}^{\delta_i} \right] , \qquad (3)$$

a Cobb-Douglas production function where $X_{i,j}$ represents the quantities of the different *j* inputs used in the agricultural production process in region $i, \alpha_{i,j}$ is the production elasticity of input *j* in region *i*, and δ_i is the output to R&D elasticity in region *i*. We fix input quantities in each region at the base period level: $X_{i,j,t} = \overline{X}_{i,j,0}$, so agricultural output in region *i* is assumed to vary only with changes in R&D stock ($RDSK_{i,t}$).

Poverty in each region *i* is a function of agricultural output and is expressed as follows:

$$Z_{i,t} = \theta_i Y_{i,t}^{\varepsilon} . \qquad (4)$$

where $Y_{i,t}$ is region i's agricultural output in year t as in equation (3), ε_i is the poverty elasticity with respect to output in region i, and θ_i is a constant term capturing the effect of factors other than output affecting poverty in region i.

The final optimization problem for year t, in the case of agricultural output maximization, is as follows:

Maximize:

$$W_t^{max} = \sum_i [\mu_{it} \times \ln(Y_{it})]$$

s.t. (5)

$$Y_{i,t} = \gamma_{i,t} \prod_j X_{i,j,t}^{\alpha_{i,j}} \left[RDSK_{i,t}^{\delta_i}\right]$$

Similarly, the poverty minimization problem is defined as follows:

Minimize:

$$W_t^{min} = \sum_i [\rho_{i,t} \times \ln(Z_{i,t})]$$

s.t. (6)

$$Y_{i,t} = \gamma_{i,t} \prod_j X_{i,j,t}^{\alpha_{i,j}} \left[RDSK_{i,t}^{\delta_i}\right]$$

$$Z_{i,t} = \theta_i Y_{i,t}^{\varepsilon}\ .$$

In both problems, the R&D stock in year t *(RDSK)* is defined as the weighted sum of annual R&D investment in the previous 10 years (*IRD* in equation [7]), assuming that there is a time lag between the investment and its effects on output. The value of the weights is defined so as to increase between $t-1$ and $t-5$ and to decrease between $t-6$ and $t-10$, following a symmetric pattern with respect to the midpoint:

$$RDSK_{i,t} = \sum_{k=1}^{10} (\beta_{t-k} \times IRD_{i,t-k})\ . \qquad (7)$$

The poverty equation, (4), is also used after solving problem (5) to calculate the number of poor that results from maximizing output across regions. As in output response to R&D, changes in poverty due to agricultural growth are also defined using poverty elasticities from the literature. No price effects are considered in the optimization problem, and the model assumes no spillovers of R&D investment to other regions.

4. UNCERTAINTY OF ELASTICITY VALUES

This paper follows a simple method for generating asymptotically consistent estimators of the population mean of the distribution of solution values, where the only source of uncertainty is the set of elasticity estimates (see De Vuyst and Preckel 1997 and Harrison and Vinod 1992). The first step in our procedure is to draw on the literature to obtain information on the two key elasticities used in our simulations: the output elasticity with respect to R&D investment and the poverty elasticity with respect to output. Tables A.1 and A.2 in Appendix A present a summary of some of the findings resulting from a literature review on this issue. The R&D elasticities for Asian countries are from Evenson. Pray, and Rosegrant 1998; Fan and Pardey 1997, 1998; and Fan 2000. They appear to be the most robust estimates from the literature. There are only three R&D elasticities for Africa, and they appear to be too low. No elasticity values were found in the literature for Latin America.

Data availability for the poverty–output elasticity are also very limited; fewer papers look at this issue than at internal rate of return (IRR) and output–R&D elasticities. The main reference for the elasticity values used in our study is the paper by Thirtle, Lin, and Piesse (2003), which estimates the impact of research-led agricultural productivity growth on poverty reduction in Africa, Asia, and Latin America.

Using the elasticity values from the literature, we followed two different procedures to define the distribution of output and poverty elasticities to better use the available information. For output–R&D elasticities we use the average value of the elasticity of Asian countries as the reference value to calibrate elasticity values for all other regions using information on rates of returns to investment in R&D. The paper by Evenson (2001) reviews the literature estimating rates of return and presents a summary table with rates of returns of agricultural R&D investment in different regions, as well as the number of studies finding similar elasticity values (see Table A.3 in Appendix A). We assume that elasticity differences among regions are proportional to IRR values and then use Asia's elasticity value from the literature and the frequencies and values from Table A.3 to define the distribution and values for R&D elasticities of all regions. Table 3 summarizes the mean elasticity values, together with the expected frequency of values around the mean as derived from the IRR values in Evenson 2001. The highest values for the output–R&D elasticities are found in Asia, and in particular in China, for which available information allowed us to define a country-specific distribution. We draw Monte Carlo samples from the elasticity distributions in Table 3 and solve the optimization model using these drawn parameters to produce estimates of means and standard deviations of model results.

Table 3. Mean values and frequency of different ranges of output–R&D elasticities for developing regions

Region	Range of elasticities						Total	Mean	Standard deviation
	0–0.043	0.044–0.087	0.088–0.129	0.130–0.172	0.173–0.216	+0.217			
Asia	15.1	16	18.9	14.2	9.4	26.4	100	0.142	0.080
China	8.8	12	18.1	19.3	11.3	30	100	0.17	0.085
Latin America	13.3	35	16.7	23.3	8.3	3.3	100	0.103	0.059
Africa	22.2	22.2	33.3	11.1	11.1	0	100	0.093	0.054

Source: Authors' calculation using information from Evenson 2001.

In the case of poverty elasticities, as the estimated values from the literature are elasticities of poverty with respect to R&D investment, we convert these elasticity values into poverty–output elasticities by dividing them by the average of our output–R&D elasticity distributions. To define distributions for poverty–R&D elasticities, we assume that it is possible to determine an appropriate a priori distribution for each elasticity (Harrison and Vinod 1992) using the information obtained from the literature to approximate the uncertain parameter distributions with a discrete set of points. We assume that variability of poverty elasticities is similar to that of output elasticities, and we use this information to determine extreme points for these distributions and use Thirtle, Lin, and Piesse's converted elasticities as their central moments. We use means and extreme values of elasticities for each region to define triangular distributions for the output–poverty elasticity values in each region. The triangular distribution is typically used as a subjective description of a population for which there are only limited sample data, given that the definition of the distribution only requires knowledge of the minimum and maximum values and a guesstimate of the modal value, which in many cases is defined by assuming a symmetric distribution around the mean.

Table 4 shows the parameters and first and second moments of the distributions for the poverty elasticities as defined above. Countries in SSA show the highest poverty elasticities—twice as high as those for Asia— whereas the lowest poverty–output elasticity values are found in Latin America.

Table 4. Parameters and moments of the assumed triangular distributions of poverty–output elasticities for different developing regions

	Poverty–output elasticity	
	Mean	SD
Sub-Saharan Africa and WANA	–2.646	1.069
Asia	–1.101	0.457
China	–0.970	0.408
Latin America	–0.274	0.111

Source: Authors' calculations

Note: The mean and variance of a triangular distribution are calculated as follows:
Mean =(a+b+c)/3; VAR=($a^2+b^2+c^2$-ab-ac-bc)/18, where *c* is the mode and *a* and *b* are the minimum and maximum values, respectively.

5. SCENARIOS AND RESULTS

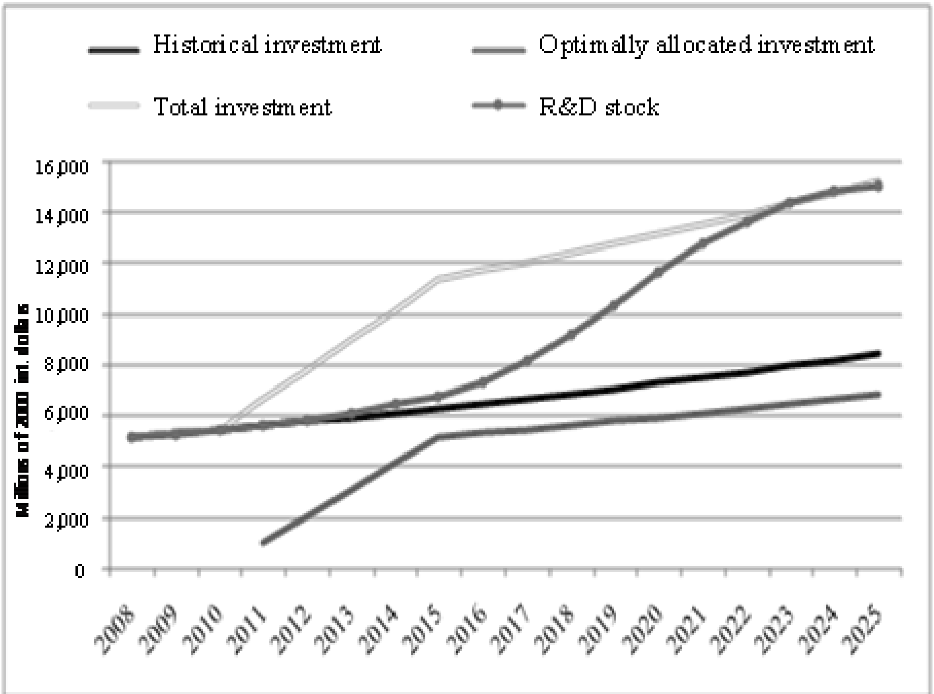
The regions considered in the analysis are SSA (comprising southern Africa, west coastal Africa, the Sahel, East Africa, and South Africa); West Asia/North Africa (WANA); China, India, and other Asian countries clustered in two groups (South Asia, East Asia, and Southeast Asia); and Latin America and the Caribbean, including the Southern Cone (Brazil, Argentina, Chile, and Uruguay), the Andean countries, Central America, and Mexico. Our simulation combines national agricultural research spending and CGIAR spending together as total spending that affects agricultural productivity in developing countries.[4] Four scenarios are considered: baseline (business as usual, or BAU), 0.5 percent annual growth in productivity, agricultural growth maximization, and maximization of reduction in the number of poor in each region:

- The baseline scenario, or BAU, assumes that research investment will continue to grow at the historical rate (1992–2000). We compare this scenario with three other scenarios:
- The first scenario assumes that R&D investment continues to grow at historical rates in each region, but growth is incremented by an additional 0.5 percentage point growth in annual productivity, which adds to the historical growth until 2025. This extra 0.5 percent productivity growth is close to the average growth of technical change in developing countries in the past 10 years (see Figure C.1 in Appendix C).
- The second scenario assumes that R&D investment continues to grow at historical rates in each region as in the first scenario, but in this scenario the incremental growth comes from exogenously doubling 2008 R&D investment in developing regions between 2010 and 2015. This new investment is then optimally allocated between these regions each year using an optimization problem that maximizes total agricultural output, subject to each region's agricultural output response to R&D, and the level of R&D stock in each region. As we assume that there is a lag between the year in which investment is made and the impact of this investment on output (see Section 3), the full impact of the optimally allocated investment in this scenario is achieved between 2020 and 2025.
- The third and last scenario, like the previous scenario, assumes that an amount equal to total R&D invested by developing regions in 2008 is allocated among these regions via an optimization problem, but in this case the problem minimizes total poverty in developing regions, subject to each region's agricultural output response to R&D and the response of poverty to agricultural output growth. As in the previous scenario, the time lag between investment and impact on output determines that the full effect of optimally allocated investment is reached after 2020.

Figure 3 shows the evolution of aggregated investment and R&D stock between 2009 and 2025 as simulated in optimization scenarios 2 and 3. The line labeled "historical investment" in Figure 3 shows the evolution of BAU investment in developing regions. The optimally allocated investment is zero before 2011 and increases linearly until 2015, when it reaches the same value as the total amount invested in 2008. After 2015 the total amount of optimally allocated investment continues to grow at historical rates. Total investment in Figure 3 results from adding total allocated and historical investment. The level of R&D stock is the one that determines output response to R&D, and as shown in the figure, it builds incorporating only a fraction of total investment of previous years. According to the evolution of R&D stocks, the total impact of investment in years 2011–2015 is achieved only by the end of the period.

[4] The CGIAR reports its spending for SSA, Asia, Latin America, and the WANA regions. We use the share of NARS spending to allocate CGIAR spending to each country or subregion.

Figure 3. Evolution of historical, new, and aggregated R&D investment and R&D stocks in the optimization scenarios



Source: Elaborated by authors.

A BAU scenario projecting growth of R&D stocks to 2025 without any exogenous increase of productivity or investment is also estimated as a reference for the results of the three main scenarios. Each scenario is estimated using two different poverty lines: $1.25 a day and $2.00 a day.

Results for the BAU scenario are presented in Table 5; Table 6 presents results for scenario 1 using the $1.25 poverty line. Under scenario 2, increasing agricultural productivity annually by 0.5 percent across all regions until 2025, an additional $10 billion will be required (above BAU growth) to sustain an annual 0.5 percent productivity increase during 17 years—a total output growth of 8.8 percent in 17 years. The 0.5 percent increase in productivity across the board requires higher R&D investment than the historical averages in regions with high levels of poverty, such as SSA. In this region, the number of poor will be reduced by 133 million in 17 years, compared with 60 million at historical rates of investment.

Table 5. R&D investment and impact on poverty and output growth under business as usual with a poverty line of $1.25/day

	R&D investment (mill. 2005 US$)		Number of poor (mill.)	Changes in the number of poor (mill.)	Agricultural productivity growth rate (%)
	2008	2025	2008	2008–2025	2008–2025
Sub-Saharan Africa	772	1492	364	–60	0.38
East Africa	287	688	140	–29	0.51
Southern Africa	88	135	12	–1	0.25
West Coast Africa	139	250	169	–24	0.34
Sahel Africa	94	170	34	–5	0.34
South Africa	164	250	9	–1	0.25
W. Asia & N. Africa	546	811	9	–1	0.23
Asia	2,864	5,132	1,002	–92	0.54
E. & S.E. Asia	1,956	3,505	304	–28	0.56
China	1,457	2,611	208	–19	0.58
South Asia	908	1,627	698	–64	0.50
India	707	1,267	569	–52	0.50
Latin America	957	1,073	44	0	0.07
Southern Cone	637	714	16	0	0.07
Andean	174	195	26	0	0.07
Mexico	146	164	2	0	0.07
Total	5,139	8,508	1,419	–153	0.42

Source: Authors' calculation based on simulations.
Note: R&D = research and development; mill. = millions.

Table 6. R&D investment and impact on poverty with 0.5 percent annual growth in productivity with a poverty line of $1.25/day

	R&D investment (mill. 2005 US$)		Number of poor (mill.)	Changes in the number of poor (mill.)	Agricultural productivity growth rate (%)
	2008	2025	2008	2008–2025	2008–2025
Sub-Saharan Africa	772	3310	363	–133	0.88
East Africa	287	1363	140	–57	1.01
Southern Africa	88	343	12	–4	0.75
West Coast Africa	139	576	169	–58	0.84
Sahel Africa	94	391	34	–12	0.84
South Africa	164	636	8	–3	0.75
W. Asia & N. Africa	546	2,097	9	–3	0.73
Asia	2,864	10,080	1,002	–182	1.04
E. & S.E. Asia	1,956	6,818	304	–53	1.06
China	1,457	5,025	208	–36	1.08
South Asia	908	3,262	698	–129	1.00
India	707	2,541	569	–105	1.00
Latin America	957	3,156	44	–1	0.57
Southern Cone	637	2,100	16	0	0.57
Andean	174	574	26	–1	0.57
Mexico	146	482	2	0	0.57
Total	5,139	18,643	1,418	–318	0.92

Source: Authors' calculation based on simulations.
Note: R&D = research and development; mill. = millions.

However, the results from the 0.5 percent across-the-board increase in productivity appear to be making an inefficient use of R&D investment, as can be seen by comparing this scenario with the BAU scenario and the optimal allocation scenarios in Tables 7 and 8. Under the second scenario, maximizing total agricultural output, average annual agricultural output will increase by 0.95 percent per year from 2008 to 2025; China and Southeast Asia are projected to grow faster than average, at 1.38 and 1.20 percent per year, respectively (Table 7).

The doubling investment and output maximizing scenario results in 261 million people moving out of poverty by 2025, compared with 153 million under historical rates of investment. Of this 261 million, 124 million live in South Asia (with 100 million in India), 78 million live in SSA (with 42 million in west coastal Africa), and 57 million live in East and Southeast Asia. The poverty impacts are still below those in the 0.5 percent productivity growth scenario (scenario 2), but it is not clear that investment in scenario 3 can lift people out of poverty more efficiently than investment in scenario 4, given that higher investment was needed in the 0.5 percent growth scenario (about a $3.3 billion difference) compared with the optimal allocation scenario. It is also clear from this scenario that to maximize agricultural output growth in developing countries, R&D investment should be allocated to East and Southeast Asia and South Asia.

Table 7. R&D investment and impact on poverty and output growth doubling investment between 2010 and 2015 and maximizing global output (poverty line is $1.25/day)

	R&D investment (mill. 2005 US$)		Number of poor (mill.)	Changes in the number of poor (mill.)	Agricultural productivity growth rate (%)
	2008	2025	2008	2008–2025	2008–2025
Sub-Saharan Africa	772	1,666	364	–78	0.51
East Africa	287	688	140	–29	0.51
Southern Africa	88	135	12	–1	0.25
West Coast Africa	139	424	169	–42	0.65
Sahel Africa	94	170	34	–5	0.34
South Africa	164	250	9	–1	0.25
W. Asia & N. Africa	546	1,047	9	–1	0.32
Asia	2,864	10,585	1,002	–181	1.20
E. & S.E. Asia	1,956	7,514	304	–57	1.29
China	1,457	6,102	208	–42	1.38
South Asia	908	3,072	698	–124	1.01
India	707	2,367	569	–100	1.00
Latin America	957	2,030	44	–1	0.44
Southern Cone	637	1,338	16	0	0.43
Andean	174	395	26	–1	0.49
Mexico	146	296	2	0	0.41
Total	5,139	15,328	1,419	–261	0.95

Source: Authors' calculation based on simulations.
Note: R&D = research and development; mill. = millions.

Under the fourth scenario (Table 8), minimizing poverty, more R&D investment should be allocated to SSA and South Asia, because most of the poor earning less than $1.25 a day live in South Asia (700 million) and in SSA (364 million). The optimal allocation of R&D investment would reduce the number of poor by 348 million in 17 years, assuming that investment at historical rates will also continue in the coming years. Of these, 171 million would be in South Asia and 147 million in SSA (with 81 million in the west coast of Africa). The poverty rate in South Asia would decrease from 48 percent in 2005 to 30 percent by 2025, which is 7 points below that in the BAU scenario. The poverty rate in Africa would decrease from 56 percent in 2005 to 25 percent, a large improvement compared with the expected poverty rate under BAU of 40 percent in 2025. Minimizing poverty requires that a large share of total R&D investment be directed to Africa.

Table 8. R&D investment and impact on poverty and output growth doubling investment between 2010 and 2015 and minimizing global poverty (poverty line is $1.25/day)

	R&D investment (mill. 2005 US$)		Number of poor (mill.)	Changes in the number of poor (mill.)	Agricultural productivity growth rate (%)
	2008	2025	2008	2008–2025	2008–2025
Sub-Saharan Africa	772	4,454	364	–146.6	1.10
East Africa	287	1,749	140	–51.9	1.04
Southern Africa	88	199	12	–2.1	0.42
West Coast Africa	139	1,829	169	–80.9	1.47
Sahel Africa	94	426	34	–10.7	0.85
South Africa	164	250	9	–1.0	0.25
W. Asia & N. Africa	546	811	9	–0.9	0.23
Asia	2,864	8,990	1,002	–200.7	0.86
E. & S.E. Asia	1,956	3,716	304	–29.6	0.58
China	1,457	2,611	208	–19.0	0.58
South Asia	908	5,275	698	–171.2	1.45
India	707	4,271	569	–141.8	1.48
Latin America	957	1,073	44	–0.2	0.07
Southern Cone	637	714	16	–0.1	0.07
Andean	174	195	26	–0.1	0.07
Mexico	146	164	2	0.0	0.07
Total	5,139	15,328	1,419	–348.4	0.71

Source: Authors' calculation based on simulations.
Note: R&D = research and development; mill. = millions.

Better results can be achieved if the efficiency of the response of output to R&D investment is improved. This idea is shown in a study by Fan (2000) that reports annual growth rates of almost 4 percent in returns to R&D investment in China between 1975 and 1997. We analyze the impact of increasing R&D elasticities over time by running the BAU and 0.5 percent productivity increase scenarios assuming increases in R&D elasticities in all regions at a similar rate of that in China as reported in Fan 2000. The final elasticity value used is within the range of the elasticity distributions defined for each region and is significantly lower than the extreme values in those distributions.

Results of the BAU and the 0.5 percent increase in productivity scenarios with enhanced efficiency are presented in Tables 9 and 10. An improvement in efficiency of R&D investment results in significant increases in the rate of growth and the number of poor people lifted out of poverty in both scenarios.

Table 9. R&D investment and impact on poverty and output growth under business as usual when poverty line is $1.25 with higher R&D efficiency

	R&D investment (mill. 2005 US$)		Number of poor (mill.)	Changes in the number of poor (mill.)	Agricultural productivity growth rate (%)
	2008	2025	2008	2008–2025	2008–2025
Sub-Saharan Africa	772	1,492	363	–90	0.61
East Africa	287	688	140	–43	0.82
Southern Africa	88	135	12	–2	0.39
West Coast Africa	139	250	169	–37	0.55
Sahel Africa	94	170	34	–7	0.55
South Africa	164	250	8	–2	0.39
W. Asia & N. Africa	546	811	9	–1	0.37
Asia	2,864	5,132	1,002	–143	0.87
E. & S.E. Asia	1,956	3,505	304	–43	0.90
China	1,457	2,611	208	–30	0.93
South Asia	908	1,627	698	–100	0.79
India	707	1,267	569	–81	0.79
Latin America	957	1,073	44	0	0.12
Southern Cone	637	714	16	0	0.12
Andean	174	195	26	0	0.12
Mexico	146	164	2	0	0.12
Total	5,139	8,508	1,418	–235	0.68

Source: Authors' calculation based on simulations.
Note: R&D = research and development; mill. = millions.

Table 10. R&D investment and impact on poverty with 0.5 percent growth in productivity when poverty line is $1.25 with higher R&D efficiency

	R&D investment (mill. 2005 US$)		Number of poor (mill.)	Changes in the number of poor (mill.)	Agricultural productivity growth rate (%)
	2008	2025	2008	2008–2025	2008–2025
Sub-Saharan Africa	772	2,812	363	–163	1.11
East Africa	287	1,178	140	–71	1.32
Southern Africa	88	286	12	–4	0.89
West Coast Africa	139	487	169	–70	1.05
Sahel Africa	94	330	34	–14	1.05
South Africa	164	530	8	–3	0.89
W. Asia & N. Africa	546	1,745	9	–3	0.87
Asia	2,864	9,160	1,002	–233	1.37
E. & S.E. Asia	1,956	6,222	304	–69	1.40
China	1,457	4,607	208	–46	1.43
South Asia	908	2,938	698	–164	1.29
India	707	2,289	569	–134	1.29
Latin America	957	2,630	44	–1	0.62
Southern Cone	637	1,750	16	0	0.62
Andean	174	479	26	–1	0.62
Mexico	146	402	2	0	0.62
Total	5,139	16,347	1418	–401	1.18

Source: Authors' calculation based on simulations.
Note: R&D = research and development; mill. = millions.

Finally, the use of $2.00 instead of $1.25 as the poverty line (Tables B.1 to B.6 in Appendix B) results in allocation patterns similar to those in previous scenarios, with the major difference being that relatively more investment tends to be allocated to Asia rather than to SSA. When using $1.25 a day as the poverty line, the share of SSA in the total number of people lifted out of poverty, under the poverty minimization scenario is 38 percent but is reduced to 32 percent (favoring Asia) when $2.00 a day is used.

Table 11 summarizes the main results of the different scenarios and the impact of investment on output growth and poverty. The most efficient way of reducing poverty in developing countries through agricultural R&D investment results from prioritizing SSA and South Asia as in scenario 3, where R&D investment is allocated to minimize poverty in developing regions. In this scenario, every $1 billion invested in agricultural R&D between 2010 and 2025 will reduce poverty by 23 million people by the end of that period when we consider a poverty line of $1.25 a day. In contrast, to accelerate agricultural growth in developing regions, the lion's share of R&D investment should go to East and Southeast Asia and South Asia, as in scenario 2. Prioritizing these regions, every $1 million invested in R&D starting in 2010 can increase agricultural growth by 1.14 percent between that year and 2025.

Table 11. Summary of the impact of agricultural R&D investment on growth and poverty under different scenarios

	Total investment (mill. 2005 US$)	Total growth 2008–2025 (%)	Change in the number of poor (mill.)	Percentage growth during 2008–2025 per $1 billion invested in R&D	Millions of people out of poverty per $1 billion invested in R&D
Poverty line $1.25 a day					
BAU	8,508	7.39	–153	0.87	–18
0.5% annual productivity growth	18,643	16.85	–318	0.90	–17
Output maximization	15,328	17.44	–261	1.14	–17
Poverty minimization	15,328	12.78	–348	0.83	–23
Poverty line $2 a day					
BAU	8,508	7.39	–272	0.87	–32
0.5% annual productivity growth	18,643	16.85	–564	0.90	–30
Output maximization	15,328	17.44	–477	1.14	–31
Poverty minimization	15,328	13.54	–599	0.88	–39

Source: Authors' calculation based on simulations.
Note: R&D = research and development; mill. = millions.

6. CONFIDENCE OF RESULTS

How confident are we of results obtained from simulations of R&D investment allocation, as they depend on the uncertainty of the R&D and poverty elasticity values used? To analyze the robustness of the results, we look at the outcome of the optimization problems (output maximization and poverty minimization) after solving each problem 500 times, each time using R&D and poverty elasticity values randomly drawn from the elasticity probability distributions defined in Section 4. Results show that even with the wide range of elasticity values considered, prioritizing East and South Asia to maximize output production and South Asia and SSA to minimize poverty yields very robust results. Table 12 shows the probability that different regions have of receiving different shares of total investment allocated to maximize output across regions. Table 13 presents similar information, but for investment allocated to minimize poverty.

Looking at regional aggregates in the output maximization scenario (Table 12), we find that the probability of Asia (East, South, and Southeast) receiving between 60 and 100 percent of total investment is 0.88. At the same time, the probability of Latin America and Africa receiving less than 10 percent of total investment is 0.53 and 0.93, respectively. Within the aggregated regions, we find that there is a 0.45 probability of China receiving more than 60 percent of total investment. Other regions with high probabilities of receiving more than 10 percent of total investment are India (0.62), other East and Southeast Asian countries (0.40), and the Southern Cone (0.33).

Table 12. Probability of allocating different shares of total R&D investment to different regions to maximize total output, given elasticity distributions for each region

	Share of total investment (%)							
	0	0–4	4–10	10–20	20–40	40–60	60–100	Total
Sub-Saharan Africa	***0.33***	***0.35***	***0.25***	***0.05***	***0.02***	***0.00***	***0.00***	***1.00***
East Africa	0.89	0.09	0.02	0.00	0.00	0.00	0.00	1.00
Southern Africa	0.90	0.10	0.00	0.00	0.00	0.00	0.00	1.00
West Coast Africa	0.33	0.35	0.27	0.05	0.00	0.00	0.00	1.00
Sahel Africa	0.94	0.06	0.00	0.00	0.00	0.00	0.00	1.00
South Africa	0.98	0.02	0.00	0.00	0.00	0.00	0.00	1.00
W. Asia & N. Africa	***0.60***	***0.17***	***0.12***	***0.09***	***0.02***	***0.00***	***0.00***	***1.00***
Asia	***0.01***	***0.00***	***0.00***	***0.00***	***0.03***	***0.07***	***0.88***	***1.00***
China	0.09	0.02	0.01	0.04	0.18	0.20	0.45	1.00
Other E. & S .E. Asia	0.28	0.13	0.19	0.29	0.11	0.00	0.00	1.00
India	0.23	0.05	0.10	0.18	0.33	0.11	0.00	1.00
Other South Asia	0.21	0.21	0.38	0.19	0.00	0.00	0.00	1.00
Latin America	***0.32***	***0.11***	***0.10***	***0.21***	***0.19***	***0.05***	***0.02***	***1.00***
Southern Cone	0.37	0.11	0.19	0.21	0.10	0.02	0.00	1.00
Andean	0.32	0.38	0.25	0.05	0.00	0.00	0.00	1.00
Mexico	0.38	0.48	0.13	0.01	0.00	0.00	0.00	1.00

Source: Authors' calculation based on simulations.
Note: R&D = research and development.

In the case of R&D investment allocation to minimize poverty, Table 13 shows that the probability of allocating more than 60 percent of all investment to Asia is 0.62, whereas for SSA it is 0.25. Among individual regions, investment to minimize poverty is most likely allocated to India and west coastal Africa. The probability of India and west coastal Africa receiving more than 40 percent of total investment is 0.53 and 0.14, respectively.

Table 13. Probability of allocating different shares of total R&D investment to different regions to minimize poverty, given elasticity distributions for each region

	Share of total investment (%)							
	0	0–4	4–10	10–20	20–40	40–60	60–100	Total
Sub-Saharan Africa	***0.07***	***0.10***	***0.09***	***0.15***	***0.19***	***0.16***	***0.25***	***1.00***
East Africa	0.26	0.12	0.15	0.20	0.23	0.05	0.00	1.00
Southern Africa	0.55	0.41	0.04	0.00	0.00	0.00	0.00	1.00
West Coast Africa	0.11	0.13	0.16	0.20	0.26	0.12	0.02	1.00
Sahel Africa	0.30	0.40	0.22	0.07	0.00	0.00	0.00	1.00
South Africa	0.89	0.10	0.00	0.00	0.00	0.00	0.00	1.00
W. Asia & N. Africa	***0.97***	***0.03***	***0.00***	***0.00***	***0.00***	***0.00***	***0.00***	***1.00***
Asia	***0.03***	***0.02***	***0.02***	***0.03***	***0.14***	***0.14***	***0.62***	***1.00***
China	0.60	0.05	0.05	0.11	0.12	0.04	0.03	1.00
Other E. & S.E. Asia	0.47	0.16	0.19	0.13	0.04	0.00	0.00	1.00
India	0.12	0.02	0.04	0.09	0.20	0.21	0.31	1.00
Other South Asia	0.17	0.14	0.24	0.33	0.11	0.01	0.00	1.00
Latin America	***0.99***	***0.01***	***0.00***	***0.00***	***0.00***	***0.00***	***0.00***	***1.00***
Southern Cone	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Andean	0.99	0.01	0.00	0.00	0.00	0.00	0.00	1.00
Mexico	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00

Source: Authors' calculation based on simulations.
Note: R&D = research and development.

7. CONCLUSIONS

This paper analyzes the effect of agricultural R&D investment on growth and poverty alleviation in developing regions to simulate how much investment is required and how it can be allocated among different regions to maximize agricultural output gains and poverty reduction. To do so, we use a transparent modeling of the global and regional agricultural research investment effects, solving a social planner's problem by means of a social welfare function to optimally allocate R&D investment across developing regions. The response of output to R&D growth is specific for each region and depends on R&D elasticity values obtained from the literature. The social planner's problem is also solved defining a global welfare function that minimizes the number of poor people across regions subject to each region's agricultural output response to R&D and the response of poverty to agricultural output growth in each region. As in the case of output response to R&D, changes in poverty due to agricultural growth are also defined using poverty elasticities from the literature. The regions considered in the analysis are SSA, WANA, China, India and other Asian countries, and Latin America and the Caribbean. The simulation combines national agricultural research spending and CGIAR spending as total spending that affects agricultural productivity in developing countries.

A first conclusion to be drawn from our results is the importance of targeting investment allocation according to goals of investors and donors. Achieving similar productivity growth in all regions results in an inefficient use of R&D investment. Second, as expected, investment priorities will differ depending on whether the goal is to maximize growth or to minimize poverty in developing regions. Our simulation results are robust for a wide range of elasticities and clearly show that to maximize agricultural output growth in developing countries, R&D investment should mainly be allocated to Southeast and South Asia. In contrast, to minimize poverty in developing regions, investment must be directed to SSA and South Asia. Third, better results in terms of growth and poverty alleviation can be achieved if the efficiency of the response of output to R&D investment is improved. Our results show that efficiency improvements, within the range of those observed in China during the 1990s, result in significant increases in the rate of output growth and the number of poor people lifted out of poverty. Finally, we observe similar allocation patterns of R&D investment when using $1.25 a day and $2.00 a day as the poverty line. The major difference observed in the results with different poverty lines is that the larger number of poor in Asia relative to Africa using the $2.00 a day poverty line results in relatively more investment being allocated to Asia rather than to SSA in both the output maximization and poverty minimization scenarios.

APPENDIX A. R&D AND POVERTY ELASTICITIES IN THE LITERATURE

Table A.1. Effects of R&D investment on agricultural production: Previous studies

Source	Country/region	Elasticity estimate		Years covered
Lusigi and Thirtle. 1997.	47 African countries	Elasticity of agricultural growth (TFP) with respect to R&D expenditure	**0.031**	1961–1991
Thirtle, Hadley, and Townsend. 1995.	22 African countries	Elasticity of output with respect to R&D expenditures	**0.015**	1971–1986
Alene and Coulibaly. 2009.	27 Sub-Saharan African countries	Elasticity of agricultural productivity with respect to agricultural research	**0.38**	1980–2003
Craig, Pardey, and Roseboom. 1997.	67 developing countries	Elasticity of labor productivity with respect to R&D expenditures	**0.093**	1961–1990
Everson, Pray, and Rosegrant 1998.	India	Elasticity of marginal TFP with respect to research expenditure	**0.045**	1956–1987
Fan and Pardey 1998.	Asia	Elasticity of R&D expenditure with respect to output	**0.1706**	1972–1993
Fan 2000.	China	Elasticity of R&D expenditure with respect to output (variable coefft. model)	**0.253**	1975–1997
		Elasticity of R&D expenditure with respect to output (fixed coefft. model)	**0.151**	1975–1998
Fan and Pardey 1997.	China	Elasticity of R&D expenditure with respect to output (with time trend)	**0.101**	1965–1993
		Elasticity of R&D expenditure with respect to output (with time trend)	**0.094**	
		Elasticity of R&D expenditure with respect to output (two-way fixed effects model)	**0.21**	

Source: Authors' elaboration.
Note: R&D = research and development; TFP = total factor productivity.

Table A.2. Effects of agricultural output growth on poverty: Previous studies

Source	Country/region	Elasticity estimate		Years covered
Fan, Zhang, and Rao. 2004.	Uganda	Elasticity of poverty with respect to. growth in agricultural production	**–0.27**	1992, 1995, 1999
Majid. 2004.	52 low- and medium-income countries	Elasticity of poverty with respect to. TFP (using Sala-i-Martin US$1poverty)	**–0.412**	Pooled 1970–2000
	52 low- and medium-income countries	Elasticity of poverty with respect to. to TFP (using ILO US$1] poverty)	**–5.24**	Pooled 1987–2000
Fan, Hazell and Thorat. 1999.	India	Elasticity of R&D expenditure with respect to. poverty	–0.065	1970–1995
Alene and Coulibaly. 2009.	27 Sub-Saharan African countries	Elasticity of poverty with respect to. agricultural productivity	–0.58	1980–2003
		Elasticity of poverty with respect to agricultural research	–0.22	1980–2003
Thirtle, Lin, and Piesse 2003.	22 African countries	Elasticity of poverty with respect to R&D	–0.26	
	11 Asian countries		–0.165	
	15 American countries		–0.03	
	All countries		–0.119	

Source: Authors' elaboration
Note: TFP = total factor productivity; ILO = International Labor Organization; R&D = research and development

Table A.3. Frequency of different ranges of internal rates of return to R&D in the literature

	Range of IRR						
Region	0–20	21–40	41–60	68–80	81–100	100+	Total
OECD	13.0	31.9	20.3	10.9	8.0	15.9	100
Asia	15.1	16.0	18.9	14.2	9.4	26.4	100
Latin America	13.3	35.0	16.7	23.3	8.3	3.3	100
Africa	22.2	22.2	33.3	11.1	11.1	0.0	100
All	14.1	26.8	19.5	14.4	8.6	16.6	100

Source: Evenson 2001.
Note: R&D = research and development; IRR = internal rate of return; OECD = Organization for Economic Cooperation and Development.

APPENDIX B. SIMULATION RESULTS WHEN THE POVERTY LINE IS $2/DAY

Table B.1. R&D investment and impact on poverty and output growth under business as usual when poverty line is $2/day

	R&D investment (mill. 2005 US$)		Number of poor (mill.)	Changes in the number of poor (mill.)	Agricultural productivity growth rate (%)
	2008	2025	2008	2008–2025	2008–2025
Sub–Saharan Africa	772	1,492	524	–86	0.38
East Africa	287	688	203	–41	0.51
Southern Africa	88	135	21	–2	0.25
West Coast Africa	139	250	235	–33	0.34
Sahel Africa	94	170	50	–7	0.34
South Africa	164	250	16	–2	0.25
W. Asia & N. Africa	546	811	41	–4	0.23
Asia	2,864	5,132	1,979	–181	0.54
E. & S.E. Asia	1,956	3,505	700	–64	0.56
China	1,457	2,611	474	–43	0.58
South Asia	908	1,627	1,278	–117	0.50
India	707	1,267	1,033	–95	0.50
Latin America	957	1,073	92	0	0.07
Southern Cone	637	714	39	0	0.07
Andean	174	195	47	0	0.07
Mexico	146	164	6	0	0.07
Total	5,139	8,508	2,636	–272	0.42

Source: Elaborated by authors.
Note: R&D = research and development; mill. = millions.

Table B.2. R&D investment and impact on poverty with 0.5 percent growth in productivity when poverty line is $2/day

	R&D investment (mill. 2005 US$)		Number of poor (mill.)	Changes in the number of poor (mill.)	Agricultural productivity growth rate (%)
	2008	2025	2008	2008–2025	2008–2025
Sub–Saharan Africa	772	3,310	523	–191	0.88
East Africa	287	1,363	203	–82	1.01
Southern Africa	88	343	21	–6	0.75
West Coast Africa	139	576	235	–80	0.84
Sahel Africa	94	391	50	–17	0.84
South Africa	164	636	14	–5	0.75
W. Asia & N. Africa	546	2,097	41	–12	0.73
Asia	2,864	10,080	1,979	–358	1.04
E. & S.E. Asia	1,956	6,818	700	–123	1.06
China	1,457	5,025	474	–81	1.08
South Asia	908	3,262	1,278	–236	1.00
India	707	2,541	1,033	–190	1.00
Latin America	957	3,156	91	–2	0.57
Southern Cone	637	2,100	38	–1	0.57
Andean	174	574	47	–1	0.57
Mexico	146	482	6	0	0.57
Total	5,139	18,643	2,633	–564	0.92

Source: Elaborated by authors.
Note: R&D = research and development; mill. = millions.

Table B.3. R&D investment and impact on poverty and output growth doubling initial investment between 2010 and 2015 and optimally allocating this investment across regions to maximize global output (poverty line is $2/day)

	R&D investment (mill. 2005 US$)		Number of poor (mill.)	Changes in the number of poor (mill.)	Agricultural productivity growth rate (%)
	2008	2025	2008	2008–2025	2008–2025
Sub–Saharan Africa	772	1,666	524	–111	0.51
East Africa	287	688	203	–41	0.51
Southern Africa	88	135	21	–2	0.25
West Coast Africa	139	424	235	–59	0.65
Sahel Africa	94	170	50	–7	0.34
South Africa	164	250	16	–2	0.25
W. Asia & N. Africa	546	1,047	41	–5	0.32
Asia	2,864	10,585	1,979	–359	1.20
E. & S.E. Asia	1,956	7,514	700	–132	1.29
China	1,457	6,102	474	–97	1.38
South Asia	908	3,072	1,278	–227	1.01
India	707	2,367	1,033	–182	1.00
Latin America	957	2,030	92	–2	0.44
Southern Cone	637	1,338	39	–1	0.43
Andean	174	395	47	–1	0.49
Mexico	146	296	6	0	0.41
Total	5,139	15,328	2,635	–477	0.95

Source: Elaborated by authors.
Note: R&D = research and development; mill. = millions.

Table B.4. R&D investment and impact on poverty and output growth doubling initial investment between 2010 and 2015 and optimally allocating this investment across regions to minimize global poverty (poverty line is $2/day)

	R&D investment (mill. 2005 US$)		Number of poor (mill.)	Changes in the number of poor (mill.)	Agricultural productivity growth rate (%)
	2008	2025	2008	2008–2025	2008–2025
Sub–Saharan Africa	772	3,714	524	–195	1.01
East Africa	287	1,475	203	–70	0.95
Southern Africa	88	192	21	–4	0.41
West Coast Africa	139	1,434	235	–106	1.34
Sahel Africa	94	364	50	–15	0.77
South Africa	164	250	16	–2	0.25
W. Asia & N. Africa	546	811	41	–4	0.23
Asia	2,864	9,730	1,979	–399	0.94
E. & S.E. Asia	1,956	4,380	700	–81	0.69
China	1,457	3,114	474	–50	0.67
South Asia	908	5,351	1,278	–318	1.48
India	707	4,289	1,033	–261	1.50
Latin America	957	1,073	92	0	0.07
Southern Cone	637	714	39	0	0.07
Andean	174	195	47	0	0.07
Mexico	146	164	6	0	0.07
Total	5,139	15,328	2,636	–599	0.75

Source: Elaborated by authors.
Note: R&D = research and development; mill. = millions.

Table B.5. R&D investment and impact on poverty and output growth under business as usual when poverty line is $2/day and regions with higher R&D efficiency

	R&D investment (mill. 2005 US$)		Number of poor (mill.)	Changes in the number of poor (mill.)	Agricultural productivity growth rate (%)
	2008	2025	2008	2008–2025	2008–2025
Sub–Saharan Africa	772	1,492	523	–130	0.57
East Africa	287	688	203	–62	0.77
Southern Africa	88	135	21	–3	0.37
West Coast Africa	139	250	235	–51	0.52
Sahel Africa	94	170	50	–11	0.52
South Africa	164	250	15	–3	0.37
W. Asia & N. Africa	546	811	41	–6	0.35
Asia	2,864	5,132	1,979	–282	0.82
E. & S.E. Asia	1,956	3,505	700	–100	0.85
China	1,457	2,611	474	–68	0.88
South Asia	908	1,627	1,278	–183	0.75
India	707	1,267	1,033	–148	0.75
Latin America	957	1,073	92	–1	0.11
Southern Cone	637	714	39	0	0.11
Andean	174	195	47	0	0.11
Mexico	146	164	6	0	0.11
Total	5,139	8,508	2,635	–419	0.65

Source: Elaborated by authors.
Note: R&D = research and development; mill. = millions.

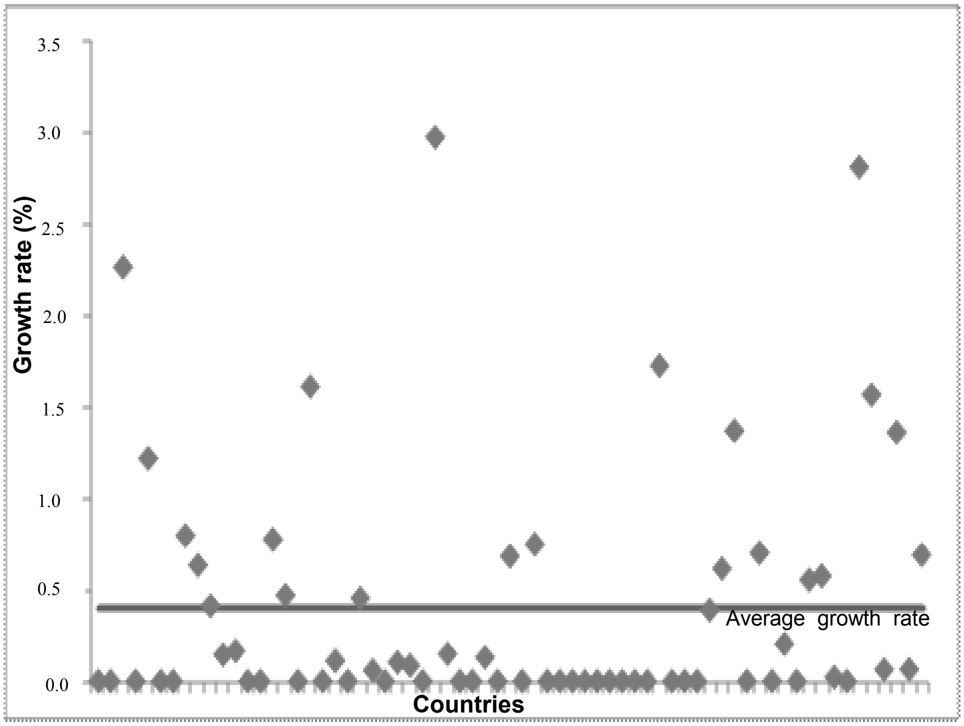
Table B.6. R&D investment and impact on poverty with 0.5 percent growth in productivity when poverty line is $2/day and regions with higher R&D efficiency

	R&D investment (mill. 2005 US$)		Number of poor (mill.)	Changes in the number of poor (mill.)	Agricultural productivity growth rate (%)
	2008	2025	2008	2008–2025	2008–2025
Sub–Saharan Africa	772	2,812	523	–235	1.07
East Africa	287	1,178	203	–102	1.27
Southern Africa	88	286	21	–8	0.87
West Coast Africa	139	487	235	–98	1.02
Sahel Africa	94	330	50	–21	1.02
South Africa	164	530	14	–6	0.87
W. Asia & N. Africa	546	1,745	41	–14	0.85
Asia	2,864	9,160	1,979	–459	1.32
E. & S.E. Asia	1,956	6,222	700	–159	1.35
China	1,457	4,607	474	–105	1.38
South Asia	908	2,938	1,278	–301	1.25
India	707	2,289	1,033	–243	1.25
Latin America	957	2,630	91	–3	0.61
Southern Cone	637	1,750	38	–1	0.61
Andean	174	479	47	–1	0.61
Mexico	146	402	6	0	0.61
Total	5,139	16,347	2,633	–712	1.15

Source: Elaborated by authors.
Note: R&D = research and development; mill. = millions

APPENDIX C. HISTORICAL GROWTH RATE OF TECHNICAL CHANGE

Figure C.1. Average value of the rate of growth (%) of technical change between 1997 and 2006 in 67 developing countries (points) and total average for the group of countries (line)



Source: Nin–Pratt and Yu 2008

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